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JULIE BILLINGSLEY
TEAM LEADER EXAMINATION
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AUSTRALIA

PATENTS ACT 1990

COMPLETE SPECIFICATION

PROVISIONAL PATENT

METHOD AND APPARATUS FOR PRECISION MEASUREMENT OF PHASE SHIFTS

The invention is described in the following statement:

METHOD AND APPARATUS FOR PRECISION MEASUREMENT OF PHASE SHIFTS

FIELD OF THE INVENTION

The present invention relates to a method and apparatus for measurement of electromagnetic phase shifts. In a particular application the invention provides an inherently stable and robust interferometer.

BACKGROUND TO THE INVENTION

Phase measurement by interferometry is at the heart of a wide range of diagnostic methods. A non-exhaustive list of applications includes spectroscopy, microscopy, gas analysis, flow analysis, pollution monitoring, monitoring thin-film deposition and stress analysis and distance measurement.

Several different types of two-beam interferometers are known in the prior art. Typical examples are the Michelson, Mach-Zehnder and Jamin interferometers. In general these apparatus operate by amplitude division, that is dividing an incident laser beam into two beams, one of which is used as a reference beam and the other which is used as a probe beam. The optical path of the probe beam is varied relative to the reference beam by its passage through, or reflection from, a test piece. The beams are recombined and interfere. The intensities of the interference fringes in the output beams are sinusoidal functions of the optical path difference introduced by interaction of the probe beam with the test piece.

It is an object of the present invention to provide an alternative to prior art interferometers that is robust and relatively insensitive to shock and vibration.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided an interferometer including:

means for splitting an input beam into a first pair of basis beams;

means for recombining said first pair of basis beams to form an output beam;

means for decomposing the output beam into a pair of analysis beams;

means for processing the pair of analysis beams to determine a relative phase shift imparted between the said first basis beams.

In a preferred embodiment of the invention the means for splitting the input beam is arranged so that the first pair of basis beams comprises respective vertically and horizontally polarized beams.

According to a preferred embodiment of the invention a polarimetric phase retrieval assembly provides the means for decomposing the output beams and the means for processing the pair of analysis beams.

Preferably the polarimetric phase retrieval assembly is arranged to calculate the phase shift on the basis of signals representing Stokes parameters associated with the pair of analysis beams.

According to a further aspect of the present invention there is provided an interferometer including:

a beam displacing assembly arranged to split an input beam into separated first and second basis beams and to combine said basis beams to produce an output beam; and

a polarimetric phase analyser responsive to the output beam and arranged to determine a difference in phase shift imparted to said basis beams.

The beam displacing assembly may include one or more polarising beam displacers and/or mirrors.

According to a further aspect of the present invention there is provided a method for detecting a phase shift imparted by a test piece including:

splitting an input beam into first and second basis beams wherein the test piece is located to interact with one of said basis beams;

recombining said basis beams to form an output beam;

analysing the polarisation state of the output beam in order to determine the phase shift.

Further preferred features of the present invention will be described in the following detailed description of an exemplary embodiment wherein reference will be made to a number of figures as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an interferometer according to a preferred embodiment of the invention.

Figure 2 is a block diagram of an interferometer according to a further embodiment of the invention.

Figure 3 is a block diagram of an interferometer according to another embodiment of the invention.

Figure 4 is a block diagram of polariametric phase retrieval module according to a preferred embodiment of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

A preferred embodiment of an interferometer 1, according to the present invention, is shown schematically in Figure 1. Interferometer 1 includes a polarising beam displacer 5 that is arranged to receive an input beam of light 4, having a known polarisation state, from laser 3. In the embodiment of Figure 1, input beam 4 is coherently split into a pair of basis beams in the form of a vertically polarised reference beam 6 and a horizontally polarised probe beam 8.

In use a test piece 7 is placed in the path of probe beam 8 as shown. Phase shift is imparted to the probe beam due to its interaction with the piece. Reference beam 6 and probe beam 8 are recombined by a further polarising beam displacer, 9, orientated inversely relative to displacer 5, to form an encoded beam 12 that is received by a polarimetric phase-retrieval module 11. The phase-retrieval module 11 generates an electrical signal that corresponds to the phase shift imparted by test piece 7.

With reference to Figure 2, if required the probe and reference beam paths can be interferometrically balanced via the addition of a suitably orientated polarising control, for example a half-waveplate 13 with its optic axis at 45°, and with the output beam displacer 15, having the same orientation as the input beam displacer 5.

An interferometer 10, according to a further embodiment of the invention is shown in Figure 3. Interferometer 10 is adapted to detect phase changes due to surface irregularities by reflection.

It will be noted that the interferometers of Figures 1, 2 and 3 are exceedingly stable as they are insensitive to relative displacements of the individual elements in the x, y and z directions. This stability is in contrast to Michelson, Mach-Zehnder, or Sagnac interferometers. Indeed, an interferometer according to an embodiment of the present invention may be configured to provide detection of extremely small rotations of, e.g. the second beam displacer 15 of Figure 2. Similarly, test piece 7 may be composed of a system of physical elements. Varying phase shifts imparted by the test physical system, for example due to vibration, may then be monitored.

If the polarization state of beam 4 is not known, or if there are systemic phase shifts in a practical realisation of the device, then removing piece 7 facilitates interferometer calibration by providing a reference state, recombined beam 12, that contains only systemic phase shifts.

Figure 4 shows one configuration of the internal components of polarimetric phase-retrieval assembly 11. Initially beam 12 is split in two by a 50-50 beam splitter 17 into beams 14 and 16. Quarter wave plate 29 transforms left and right circular components of beam 14 into corresponding vertical and horizontal components of beam 18. Accordingly, polarising beam-splitter 31 splits beam 18 into separate horizontally and vertically polarised component beams 20 and 22 respectively. The intensity of the horizontally polarised beam 20 is detected by photodetector 33 which produces a corresponding electrical signal on cable 24. The intensity of the vertically polarised beam 22 is detected by photodetector 35 which produces a corresponding electrical signal on cable 26. The intensity signals are appropriately scaled and differenced by pre-processor 37, for example a suitably configured operational amplifier, to produce a signal corresponding to the S3 Stokes parameter on cable 38.

Beam 16 from splitter 17 is incident upon a half wave plate 19 which transforms diagonal and anti-diagonal components in beam 16 into corresponding horizontal and vertical linearly polarized components of beam 28. Polarizing beam splitter 21 splits beam 28 into horizontally and vertically polarized component beams 32 and 30 respectively. The intensity of horizontally polarised beam 32 is detected by photodetector 25 to produce a corresponding electrical signal on cable 36. The intensity of the vertically polarised beam 30 is detected by photodetector 23 which produces a corresponding electrical signal on cable 34. The intensity signals on cables 36 and 34 are appropriately scaled and differenced by pre-processor 27 to produce a signal corresponding to the S2 Stokes parameter on cable 40.

The S2 and S3 signals from pre-processors 27 and 37 are processed by processing module 39 to calculate $\phi = arctan(S3/S2)$ which is the phase difference imparted by piece 7. In one implementation, processing module 39 includes a suitably programmed fast digital processor and associated analog-to-digital converters to calculate the arctangent function. The processing module may also control a digital display 43 for generating a visual readout of ϕ.

It will be realised that the present invention involves, decomposing the output beam 12 into a pair of analysis beams that are analysed in bases different to that used to construct the input. Each component in the new bases can be expressed as a linear superposition of components of the original basis, beams 6 and 8, with a known relationship between them. Thus this relationship may be used to extract the relative phase shift between the reference and probe arms. This is then, exactly, the phase shift imparted to electromagnetic radiation by the physical system under study.

The S_2 and S_3 detectors may be configured to measure the temporal variation in the output, the spatial variation in the output, or both. That is, the photodetection part of the detectors may include, but are not limited to, single element detectors (for example, PIN photodiode or PMT) or spatial imaging components (for example, CCD or CMOS camera). In the latter case, the signal processing must be applied on a pixel by pixel basis.

Referring again to Figures 1, 2 and 3, the beam displacers shown in those figures are relatively insensitive to changes in wavelength over a broad range. Thus the device may be used to measure phase shifts of multiple wavelengths simultaneously. For example, input beam 4 might include a fundamental frequency and its second harmonic, a mixture of several laser lines or the output from a number of lasers. Alternatively it could comprise a frequency comb, for example a "white-light" comb produced by photonic band gap materials. The output may be first separated into wavelength components and then phase analysed with S2 and S3 detectors, or more practically, first split into S2 and S3 detector arms which incorporate broadband polarisation optics, and then wavelength analysed, before the photodetection element. Cellophane may be used to implement a satisfactory broadband waveplate.

Further variations and embodiments in addition to those explained herein are possible, for example, the output beams of the first beam displacer can be directed through appropriate polarisation rotation elements to a retroreflecting element. Depending on the geometry of this element, the beams may then exit along the same path as they entered (similar to a Sagnac interferometer), or a separate path (similar to a displaced Sagnac interferometer). This configuration means that both beams experience the same distortions due to any imperfections in the first beam displacer.

The embodiments of the invention described herein are provided for purposes of explaining the principles thereof, and are not to be considered as limiting or restricting the invention since many modifications may be made by the exercise of skill in the art without departing from the scope of the invention.

Dated this 27th day of August 2003

The University of Queensland

by my attorneys
Eagar Newcomb & Buck

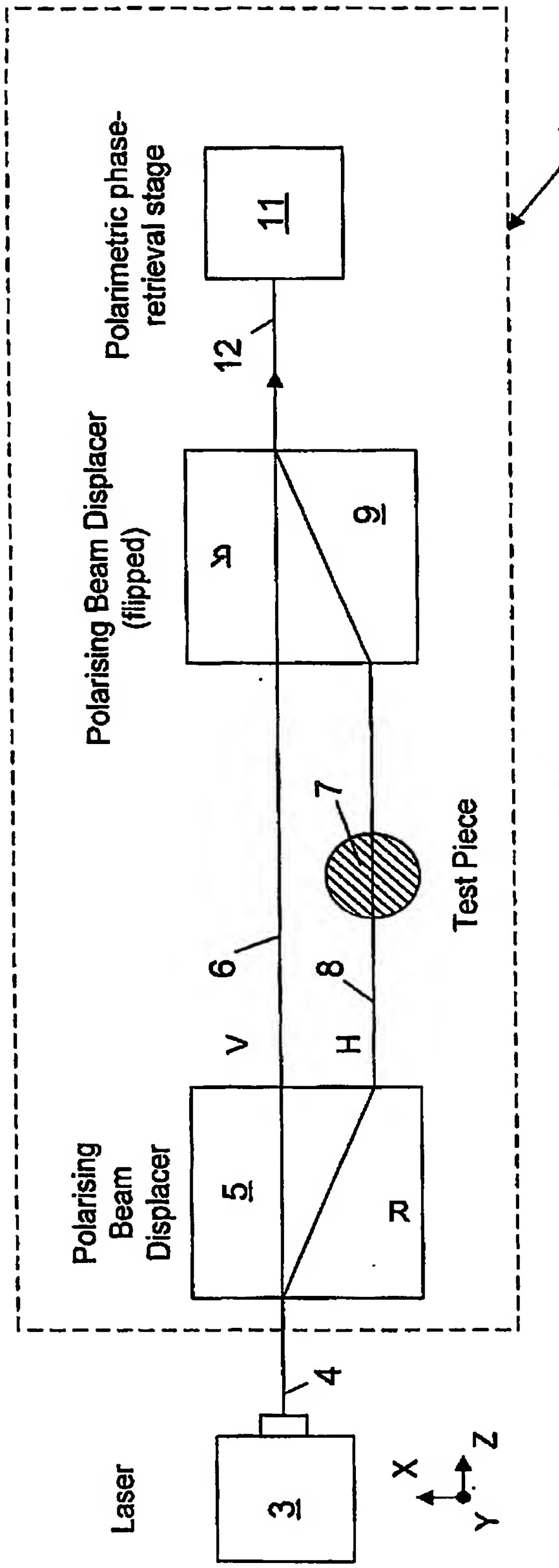


Figure 1

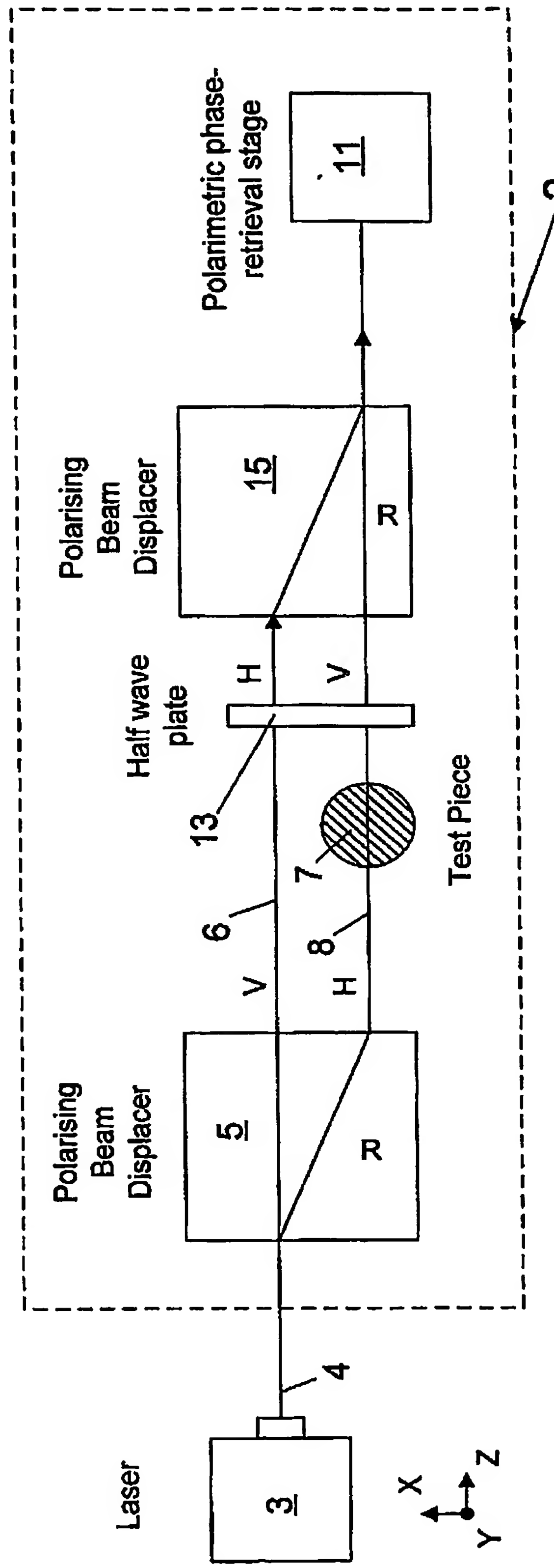
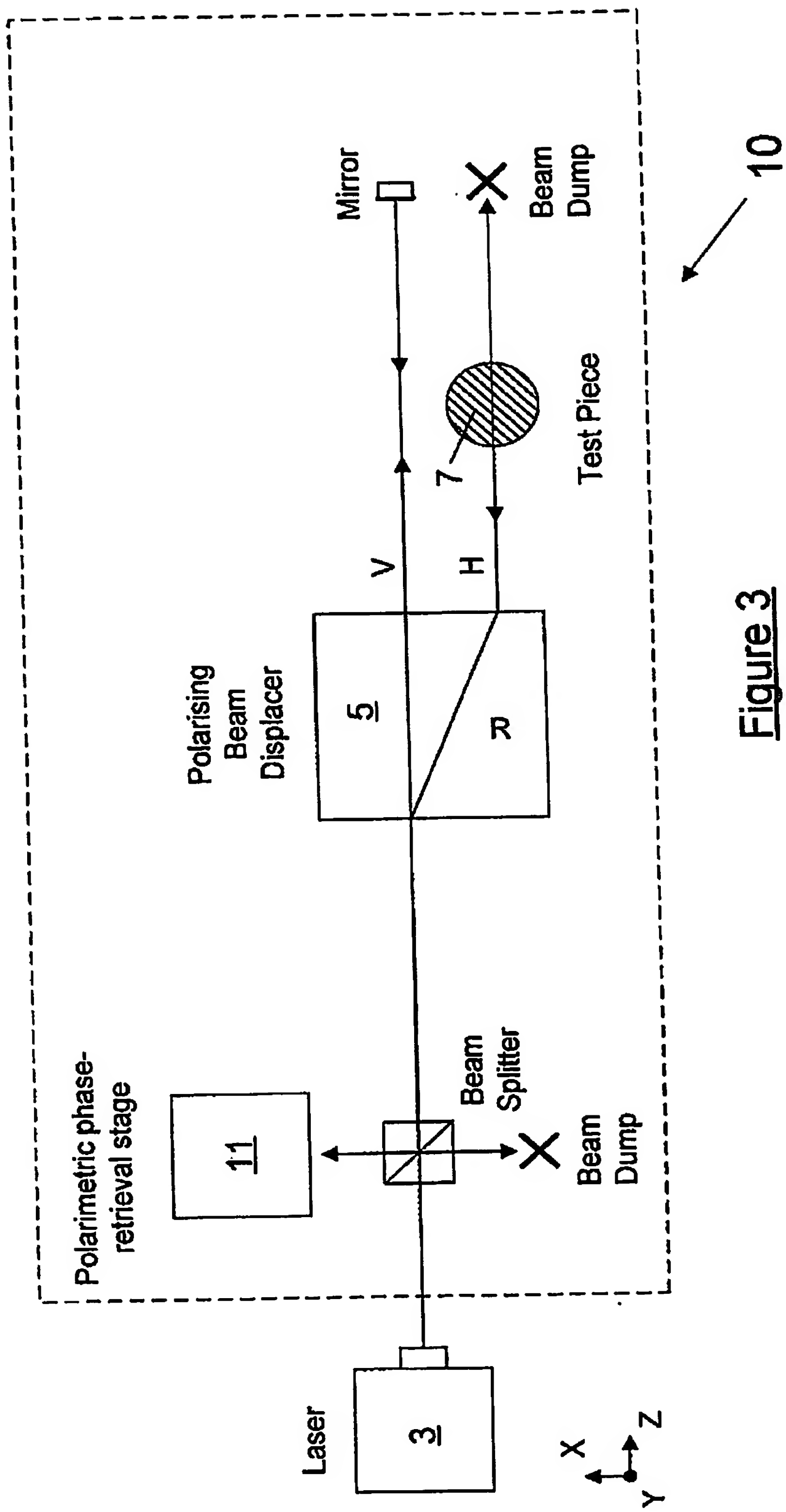
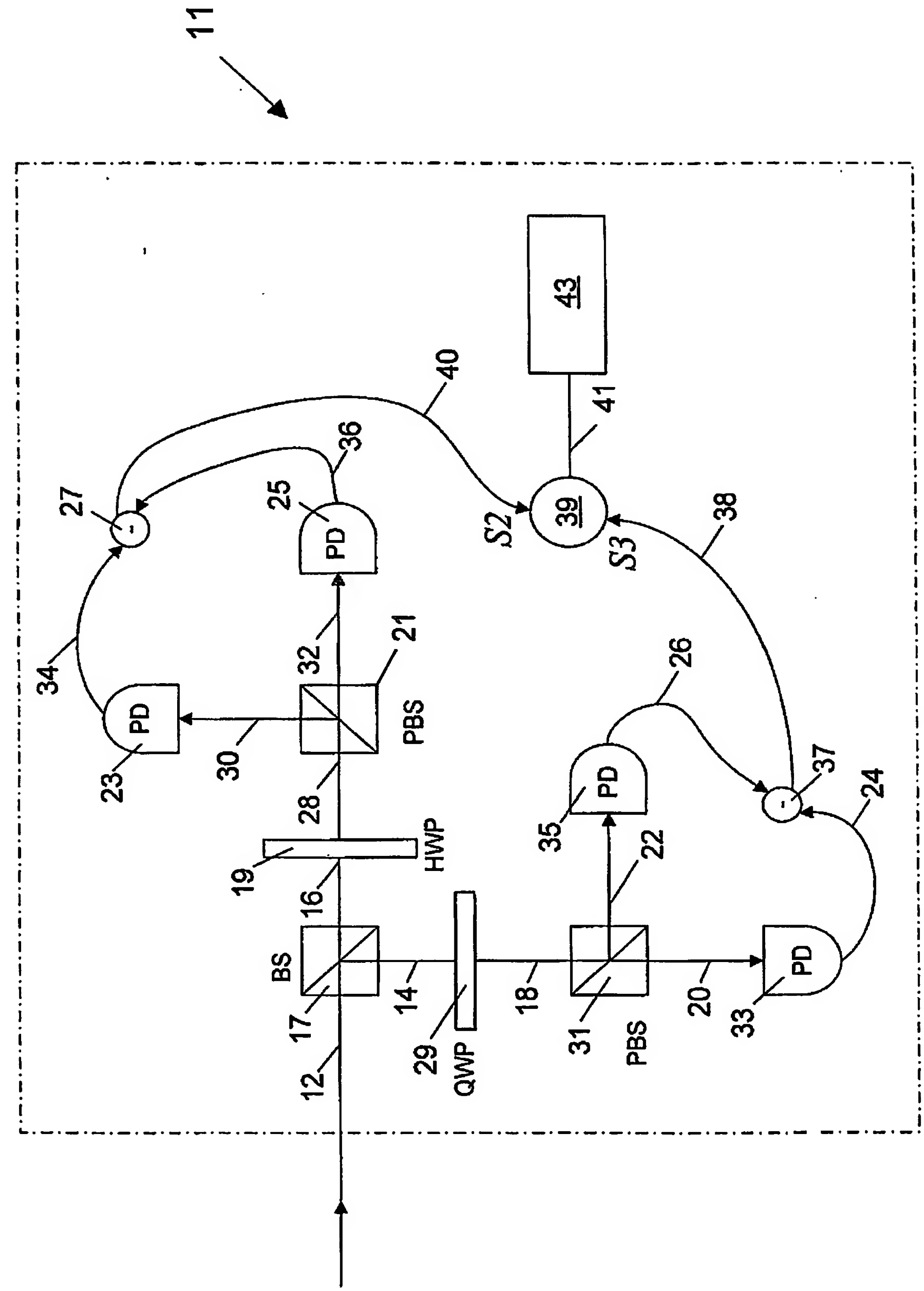


Figure 2



Polarimetric phase-retrieval stage
11
Beam Splitter
Beam Dump
Laser
3
X
Y
Z
Polarising Beam Displacer
5
R
V
H
7
Test Piece
Mirror
Beam Dump
10

Figure 3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PBS
PBS
HWP
QWP
PD
PD
PD
PD
S2
S3

Figure 4